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Abstract

Increasing attention is being paid to the Paris Climate Agreement and the impacts of Nationally Determined Contributions (NDCs) intended to limit global warming to 1.5 °C. However, the nature and evolution of existing policy mixes that underlie NDCs remain poorly understood. This critical issue has emerged from the outcomes of the Talanoa Dialogue for Climate Ambition, where little progress was made in building a comprehensive, evidence-based foundation for effective climate policy. To a large extent, this is due to the nature of the process, and a lack of data related to policy interventions in the pre-2020 period, notably their composition, coverage, and orientation. We seek to address these shortcomings by applying a directed content analysis to a dataset of national and city-level policy interventions. The aim is to quantify the nature and evolution of policy efforts that promote the adoption of low-carbon energy technologies (LCETs) globally. Fifteen databases, containing more than 10,000 policies and measures were reviewed. Our findings highlight the rapid spread of policy portfolios and an international convergence towards economic incentives (notably subsidies). At the city level, technology and infrastructure policies dominate. However, it is unclear to what extent behavioural factors (i.e., cognitive, motivational and contextual aspects) that affect the choice and use of LCETs are taken into account in policy design. This is particularly important because studies that model the feasibility of the 1.5 °C target reveal behavioural changes and the rapid adoption of low-carbon lifestyles as critical enabling factors. In response to the outcomes from the Talanoa Dialogue, we argue that policymakers need to go beyond stringent policy mixes and rapidly re-think their traditional economic-driven policymaking approach. Far more attention needs to be given to behavioural factors when designing, evaluating and implementing LCET policies.

1. Introduction

Nationally Determined Contributions (NDCs) are at the heart of the Paris Climate Agreement, and their analysis has attracted growing attention from scholars, policymakers and practitioners [1–5]. The 2018 Intergovernmental Panel on Climate Change (IPCC) *Special Report on Global Warming of* 1.5 °C found a significant gap between the emission reductions that NDCs can potentially deliver and those that are needed to limit global warming to 1.5 °C [6]. Typically, the gap is said to be due to insufficiently rigorous near- and long-term mitigation policies [1, 7, 8]. Despite increasing attention to the NDCs, the Paris Agreement (1/CP.21/II-17) emphasises the point, stating that 'much greater emission reduction efforts will be required than those associated with the intended nationally determined contributions in order to hold the increase in the global

average temperature to below 2 °C above pre-industrial levels' [9]. Therefore, much greater consideration needs to be given to developing policy portfolios that limit climate change, beyond NDCs.

In this context, the 2018 Facilitative Dialogue (known as the 'Talanoa Dialogue for Climate Ambition') was launched at the 23rd Conference of the Parties (COP23) to the United Nations Framework Convention on Climate Change (UNFCCC). Work started in January 2018 to support the long-term policy efforts related to the Paris Agreement. The mandate was to take stock of global policy efforts, particularly in the run up to 2020, designed to achieve the long-term goal of the Paris Agreement (stated in Article 4, paragraph 1) and to inform the development of NDCs in accordance with Article 4, paragraph 8, of the Agreement[6]. In principle, the Talanoa Dialogue marked the beginning of the process of strengthening NDCs, and the key questions guiding the initiative were: 'where are we?', 'where do we want to go?' and 'how do we get there?' [10]. Both the preparatory and political phases have now concluded, and a report was published in November 2018[7].

When scrutinising the results of the Talanoa Dialogue, the understanding of pre-2020 policy interventions ('where are we?') appears limited and inadequate. First, reporting and data availability were major challenges. Unlike NDCs, which can be easily accessed via the UNFCCC registry [11], data of pre-2020 policy interventions are dispersed over multiple sources. Second, input from the Parties was marginal. Of the 473 inputs received by October 2018, only 44 (9%) came directly from them (see 12). Of these, 37 (7%) specifically addressed the question 'where are we?', and the answers covered a wide range of issues (e.g. emission trends, climate impacts, vulnerability, and institutional arrangements). In fact, policy issues were mostly addressed by non-Party stakeholders. The third issue is that the effectiveness of policy interventions and their evolution were only examined superficially and a lack of (self-) criticism is identified[8]. Examples include statements such as, '[policy] action to build a low-emission and climate-resilient society is expanding' and 'further and faster climate action [is possible] provided that barriers are addressed and efforts to create an enabling environment increased' [12]. Key barriers were said to include a lack of political will, shortcomings in existing policy frameworks, and a lack of finance. Interestingly, a recurring claim was made that opportunities for improving *existing* policy interventions depend on 'demands for an adequate Paris Agreement work programme to be adopted at COP24' [12]. Fourth, the resulting report on Good Practices [13] emphasises developments in technology and the use of economic incentives across key sectors such as energy and transport. Here, one wonders whether the lack of inputs from Parties prevented the treatment or identification of a wider set of policy interventions. While there is increasing evidence that, in theory, technological measures can help to meet the 1.5 °C target [6], modelling studies critically highlight the need for rapid changes in behaviour and lifestyles to limit climate change [14, 15]. Thus, the strong focus on technologies seems incompatible with growing calls for more behavioural-oriented policy interventions [14, 16, 17]. This is despite the fact that 'psychological factors (e.g. short-termism and self-interest)' [12] were identified by the Talanoa Dialogue as a critical barrier for more effective policy action.

In all, we argue that the Talanoa Dialogue has failed to clearly characterize the nature and evolution of policy portfolios that underlie NDCs. This was most likely due to its limited scope, combined with a lack of data and systematic reporting regarding the national and non-state measures already in place. Consequently, the process was dominated by 'a collection of ideas, rather than a set of conclusions' [10]. Altogether, these challenges made it difficult to establish a more comprehensive overview of past experience and use it to advance future policymaking (i.e. 'how do we get there?').

Here, we aim to address this gap. The purpose of our study is to quantify the nature and evolution of low-carbon energy technology (LCET) policy interventions. We combine historical evidence of policy implementation efforts with a directed content analysis. Our study aims to provide important insights for policymakers. We limit our analysis to policies and measures that encourage the adoption and use of renewable energy and energy-efficiency technologies. The agricultural and forestry sectors are excluded. Given the mandate of the Talanoa Dialogue, we address policy interventions at the national and city level. The latter is critical because cities can lead the way in climate change action [18], and bottom-up initiatives are pivotal in closing the emissions gap left by NDCs [19, 20]. We focus on two main areas: policy instruments (i.e. economic incentives, regulations, information schemes and voluntary agreements); and behavioural factors (i.e. cognitive, motivational and contextual aspects) that prevent or promote sustainable energy behaviour [17, 21, 22]. In turn, we conceptualise behavioural-oriented interventions as any policy instrument (e.g. economic incentive) or policy measure (e.g. practices, processes) that either explicitly incorporates behavioural factors (i.e. cognitive, motivational and contextual aspects) into its design, or is deliberately intended to address the constraints, biases

[6] Paragraph 8 in Article 4 of the Paris Agreement states that 'In communicating their nationally determined contributions, all Parties shall provide the information necessary for clarity, transparency and understanding in accordance with decision 1/CP.21 and any relevant decisions of the Conference of the Parties serving as the meeting of the Parties to this Agreement'.

[7] Reports are publicly available at https://talanoadialogue.com/

[8] We acknowledge that the lack of criticism was likely to have been driven by the nature of the process and framed by the meaning of the 'Talanoa' tradition, which encourages participants to avoid blaming others and making critical observations.

and the context of human decision making (e.g. via choice defaults to promote green electricity, social norm information campaigns to promote energy conservation). Further details are given in the next section.

Our study extends previous assessments about the development of climate and energy policy mixes [23, 24–26], including studies of measures and commitments by non-state actors [27, 28].[9] Notably, these efforts have focused on specific aspects of climate policy (e.g. climate legislation or top-level policies) in a limited number of countries (e.g. industrialised nations), over relatively short periods, and largely ignored policies that explicitly target behavioural factors. Strikingly, although claims have been made that behavioural factors are overlooked by policymakers [21, 29], such claims remain unsupported. Yet multiple behavioural factors have been shown to play a key role in LCET-related human decision making processes [21, 22, 30–32]. Furthermore, there is growing evidence that the inclusion of behavioural factors is consistent with (cost-) effective policy interventions [14, 30, 33]. Modelling studies show a significant short-term mitigation potential through behavioural change: 20% in the United States [34] and up to 16% in the European Union [35]. With due limitations, our study aims to address these points.

2. Methodological approach

We analysed national (top-down) and city-level (bottom-up) policy interventions that promote or encourage the market uptake of LCET technologies. The dataset consisted of various databases (details below), which were the subject of a directed content analysis. The latter involves examining documentary evidence [36] following existing conceptual frameworks (e.g. from behavioural economics or environmental psychology) and prior research (e.g. policy evaluation) [37]. The approach involves counting and comparing keywords followed by the interpretation of trends and patterns [37]. In our case, the analysis aimed to understand the nature and evolution of policy portfolios that support NDCs under the Paris Climate Agreement.[10]

First, five categories were defined: (1) geographical coverage, (2) policy instruments at the national level, (3) policy instruments at the city level, (4) orientation of policy design and mitigation actions, and (5) policy status (see table 1). For the top-down analysis, we divided the world into eight geographical regions (Category 1), and individual countries were categorised as a function of the geographical scope of each region.

Categories 2 and 3 refer to top-down (national) and bottom-up (city) perspectives, respectively. We defined policy interventions as any course of action, programme or activity taken or mandated by national or local actors that seeks to encourage sustainable energy behaviour through the adoption and use of LCET. No distinction was made with respect to the potential for emissions reductions. National-level policy instruments were defined using the taxonomy given in the 5th IPCC Assessment Report Working Group III [38], which lists the following: (i) economic incentives that alter the conditions and behaviour of market agents via price mechanisms (e.g. taxes, subsidies, emissions trading); (ii) direct regulatory approaches involving mandates or rules that subject participants must fulfil (e.g. building codes, minimum performance standards); (iii) information schemes that provide comprehensive and accurate information to consumers and producers (e.g. education, public awareness campaigns and labelling programmes), and (iv) voluntary actions between the private sector and the government to meet a given objective or target (e.g. GHG emission reduction pledges, sectoral energy efficiency targets). Specific policy instruments were thus used as keywords. The list of city-level policy actions (Category 3) followed the taxonomy provided by the Carbon Disclosure Project (CDP) [39]. The CDP database was the principal source of information for developing Category 3 and, overall, it offered the best classification of policy instruments (and commitments) from a longer-term perspective (2012 to 2017).

Category 4 addressed whether behavioural factors are indeed being overlooked by policymakers [21, 29]. Specifically, we examined whether policies aim to address market failure or behavioural factors. Market failures were conceptualised as flaws in the market (e.g. information asymmetries, negative externalities) that prevent an efficient allocation of LCETs [38, 40]. Behavioural factors were conceptualised in terms of behavioural anomalies (or 'irrationalities') and motivational aspects. The former are defined as behaviours that are inconsistent with rational choice theory and thus yield suboptimal outcomes [41, 42]. Deviations from rational choice are not necessarily erratic, but can lead to systematic differences between decision utility (i.e. expected or intended utility at the time of choice) and experienced utility (i.e. utility experienced after the choice) [42]. Motivational aspects were defined as the reasons to engage in sustainable energy behaviours (e.g. pleasure, altruism, social norms), including contextual factors that define or affect the costs and benefits of energy behaviours and therefore individual motivations [43]. Together, these behavioural factors help in understanding why policy interventions do not always yield the expected effects [14, 38]. In the context of climate change mitigation and energy use, we were guided by, for example, self-control problems, reference dependent preferences, heuristics, limited attention, procrastination and status quo bias [21, 22, 29, 31, 44]. Policies were coded as 0 (no explicit inclusion) and 1 (explicit inclusion). We used the taxonomy of choice policy architecture techniques developed by Münscher *et al* [45] targeting judgment and decision making to identify explicit

[9] We do not know whether or not existing studies about policy development and performance were considered by the Talanoa Dialogue.
[10] All data sources are publicly available. Our material is available upon request.

Table 1. Categories, items and coding in directed content analysis.

Category 1: Geographical coverage		
Sub-category	Searched items	Code
Africa	Algeria, Angola, Benin, Botswana, Cameroon, Congo, Dem. Rep. Of Congo, Côte d'Ivoire, Egypt, Eritrea, Ethiopia, Gabon, Ghana, Kenya, Libya, Morocco, Mozambique, Namibia, Nigeria, Senegal, South Africa, Sudan, United Rep. Of Tanzania, Togo, Tunisia, Zambia, Zimbabwe, other Africa	1
Asia	Bangladesh, Brunei, Cambodia, Hong Kong (China), India, Indonesia, Israel, Japan, DPR of Korea, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, People's Rep. of China, Philippines, Singapore, South Korea, Sri Lanka, Taiwan, Thailand, Vietnam, other Asia	2
Latin America (Latam) & the Caribbean	Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Jamaica, Netherlands Antilles, Nicaragua, Panama, Paraguay, Peru, Trinidad and Tobago, Uruguay, Venezuela, other Americas	3
Middle East	Bahrain, Islamic Rep. of Iran, Iraq, Jordan, Kuwait, Lebanon, Oman, Qatar, Saudi Arabia, Syrian Arab Republic, United Arab Emirates, Yemen	4
Non-OECD Europe & the Former Soviet Union (FSU)	Albania, Armenia, Azerbaijan, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Cyprus, Georgia, Gibraltar, Kazakhstan, Kosovo, Kyrgyzstan, Latvia, Lithuania, FYR of Macedonia, Malta, Republic of Moldova, Montenegro, Romania, Russian Federation, Serbia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, USSR (former), Yugoslavia (former)	5
Oceania	Australia, New Zealand	6
OECD Europe	Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Portugal, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom	7
OECD North America	Canada, Mexico, United States	8
Category 2: Policy instruments at the *national* level		
Sub-category	Searched items	Code
Economic incentives	Subsidy, grant, loan, tax credit, rebate, carbon tax, carbon pricing, emission trading scheme, procurement, tender programme, tradable green certificate, tradable energy efficiency certificate, energy saving trading, subsidy removal, performance contracting, R&D funds	1
Regulatory approaches	Performance standard, minimum standard, emission standard, monitoring plan, obligation, quota, building codes, building standards, compulsory auditing, guarantee of origin, mandatory target, regulation, binding legislation	2
Information schemes	Certification, information centre, technical assistance, awareness raising, educational campaign, labelling scheme, feedback, rewards, public awareness	3
Voluntary actions	Energy efficiency accord, optional target, chosen renewable target, emission reduction target, sectoral target, discretional energy saving programme, voluntary labelling scheme, voluntary agreement	4
Category 3: Policy actions at the *city* level		
Sub-category	Searched items	Code
Technology & infrastructure investments	Energy efficiency/ retrofit measures, improve fuel economy and reduce CO_2 from vehicles Infrastructure for non-motorized transport, recycling or composting collections and/or facilities Low or zero carbon energy supply generation, improve bus infrastructure, services, and operations, on-site renewable energy generation, LED / CFL / other luminaire technologies, recyclables and organics separation from other waste, improve rail, metro, and tram infrastructure, services and operations, water recycling and reclamation, switching to low-carbon fuels, landfill management, wastewater to energy initiatives, smart grid, carbon emissions reduction from industry, optimize traditional power/ energy production, improve the efficiency of waste collection, smart lighting, improve the efficiency of freight systems, improve the operations of shipping ports, transmission and distribution loss reduction, improve the efficiency of long-haul transport	1
Information & awareness	Waste prevention policies and programs, awareness and education for non-motorized transport Transportation demand management, building performance rating and reporting, Encourage sustainable food production and consumption, smart public transport, water metering and billing	2

Table 1. (Continued.)

Category 1: Geographical coverage		
Sub-category	Searched items	Code
City planning	Green space and/or biodiversity preservation and expansion, transit oriented development Eco-district development strategy, urban agriculture, compact cities, brownfield redevelopment programs, low-carbon industrial zones	3
Regulation	Building codes, building standards	4
Other	Developing the green economy, instruments to fund low carbon projects, other	5
Category 4: Orientation of policy design and mitigation actions		
Sub-category	Searched items	Code
Market failures	Information asymmetry, non-competitive markets, externalities, public goods	0
Behavioural factors	Self-control, reference dependent, heuristics, limited attention, procrastination, status quo bias, irrational behaviour, contextual motivation, behavioural anomalies, bounded rationality, bounded willpower, bounded self-interest, cognitive bias, social norms, nudge, framing, loss/ risk aversion, behavioural economics, discounting, satisficing, salience	1
Category 5: Policy status		
Sub-category	Searched items	Code
Ended	Ended, terminated, phased-out, cancelled, superseded	0
Enforced	Implemented, enforced, in-force, on-going	1

Table 2. Reviewed databases.

For policy instruments at the *national* level	Source
Asian Development Bank (Country and Sector project database)	http://adb.org/projects
African Development Bank Group (Project and Operations database)	http://afdb.org/en/projects-and-operations/
Economic Commission for Latin America and the Caribbean (Country profiles and statistics)	http://estadisticas.cepal.org/cepalstat/WEB_CEPALSTAT/Portada.asp?idioma=i
International Energy Agency (Climate Change, Renewable Energy, Energy Efficiency database)	http://iea.org/policiesandmeasures/
International Center for Climate Governance (Climate Policy Observer database)	http://climateobserver.org/country-profiles/
International Institute for Sustainable Development (Sustainable Energy/Climate Change Policy and Practice)	http://sdg.iisd.org/
Inter-American Development Bank (Political Institutions, State Capabilities, and Public Policy: An International Dataset)	https://mydata.iadb.org/Reform-Modernization-of-the-State/Political-Institutions-State-Capabilities-and-Publ/j6yb-w5eq
Global Climate Legislation database	http://lse.ac.uk/GranthamInstitute/research-theme/governance-and-legislation/
NewClimate Institute (Climate Policy Database)	http://climatepolicydatabase.org/
World Bank (Project and Operations database)	http://worldbank.org/projects?lang=en
World Resource Institute (SD-PAMs database)	http://projects.wri.org/sd-pams-database
For policy actions at the *city* level	Source
Climate Disclosure Project open data portal	https://data.cdp.net
Carbonn® registry	http://carbonn.org/entities
Covenant of Mayors	http://covenantofmayors.eu/plans-and-actions/good-practices.html
UNFCCC NAZCA database	http://climateaction.unfccc.int/cities

behavioural-oriented interventions. There are three categories: (a) decision information (a choice architecture that targets the presentation of decision-relevant information, for example, social reference points); (b) decision structure (a choice architecture that targets the arrangement of options and decision-making format, for example, choice defaults); and (c) decision assistance (a choice architecture that targets self-regulation so that decision-makers can materialise their intentions, for example, commitment).

Finally, Category 5 addressed the status of policy interventions (both national and city-level). Specifically, it looked at whether policies and/ or measures were still being enforced or had ended.

In terms of data, our analysis aimed to examine a representative cross-section of decarbonisation policy interventions. A total of 15 databases (see table 2), containing more than 10,000 policies and measures were

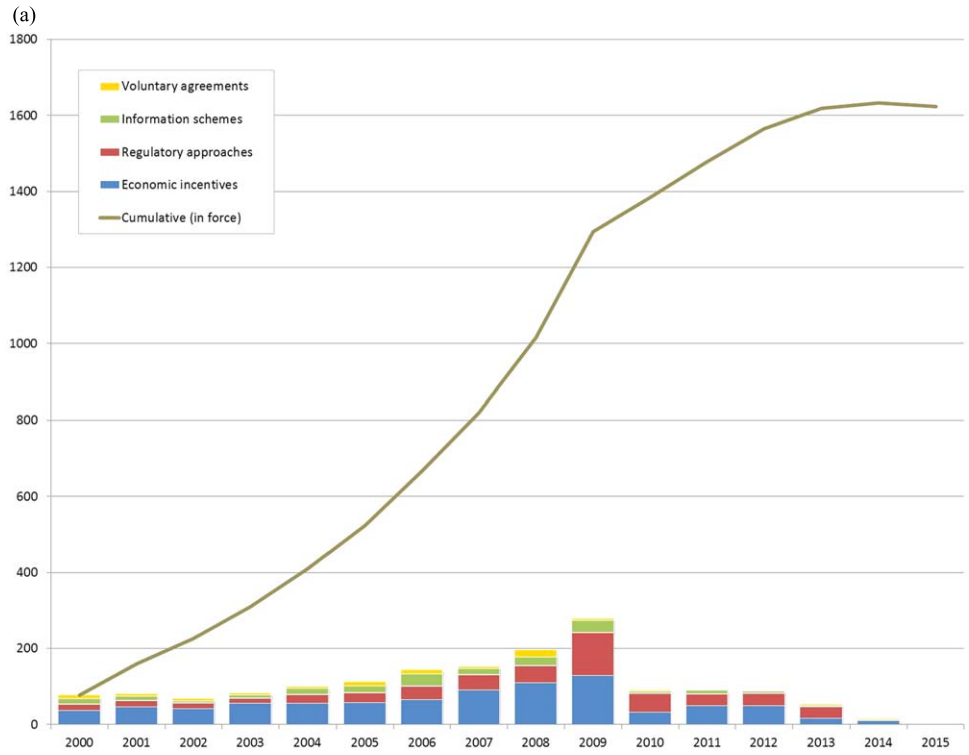


Figure 1. (a) Evolution of global LCET policy interventions over the period 2000–2015. Bars show net annual additions (i.e. frequencies). Cumulative (in-force) interventions are shown by the solid line; (b) Composition of implemented policy interventions per region in 2015. The number of identified, enforced policies is shown in parenthesis. (c) Global breakdown of implemented (in-force) economic incentives in 2015.

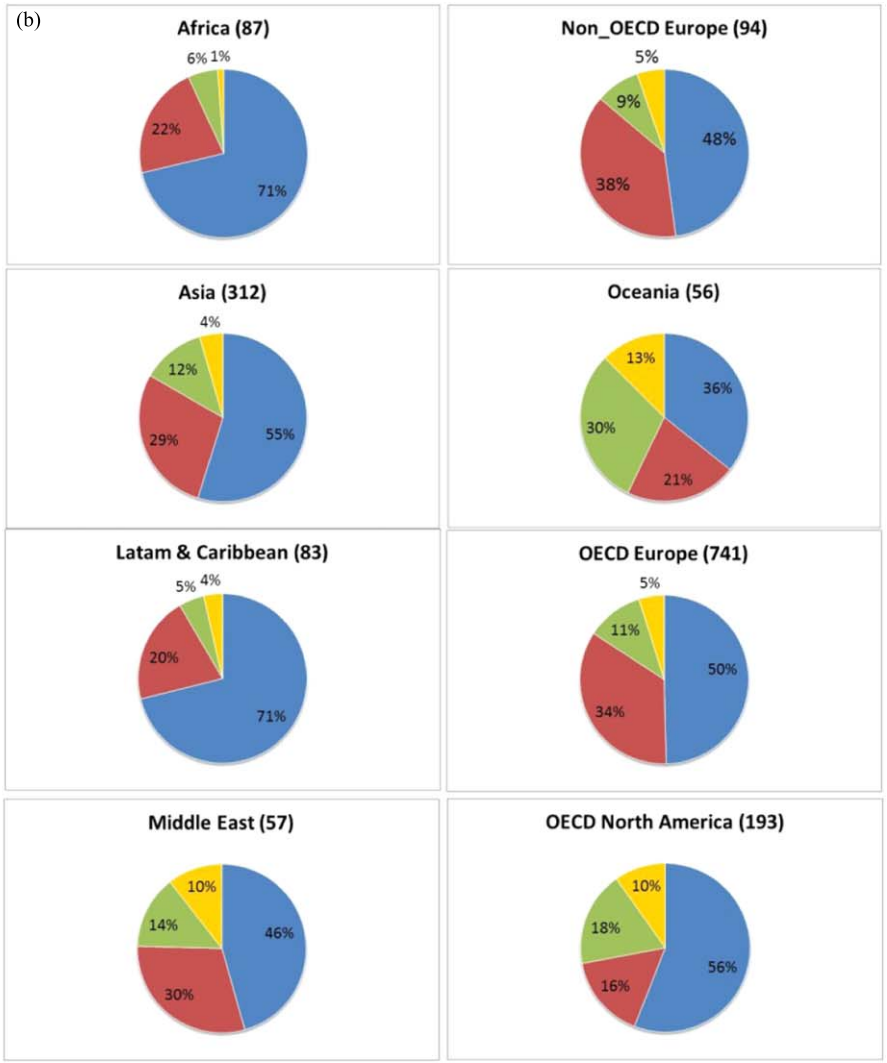
reviewed. Although by no means exhaustive, the top-down analysis included 11 databases provided by a wide variety of organisations (see column 1). This information was supplemented by peer-reviewed material and country-specific official documentation. Data covered the period 2000–2015. The bottom-up (city-level) review was based on several climate-energy networks and their respective databases of mitigation actions (see table 2). This included 'good practices' reported by signatories to the European Covenant of Mayors [46], climate actions undertaken by the Global Covenant of Mayors for Climate and Energy [47], entries in the International Council for Local Environmental Initiatives (ICLEI) carbonn® registry [48], UNFCCC's collection of climate actions by cities [49], and emission reduction activities reported to the CDP [39]. Climate actions are self-reported by cities and interventions included in the different databases overlap; typically they are a mixed collection of commitments, strategies, action plans and actual policy instruments. While the first transnational municipal climate networks were developed around twenty years ago, extensive data is only available for the past five to ten years. The problem of overlaps and differences in categorising climate actions meant that entries from different databases were not merged. The city-level review covered the period 2012–2017 and data was also supplemented by peer-reviewed material.

3. Results and discussion

The top-down analysis yielded three important results (figures 1(a)–(c)). First, there has been significant growth in LCET policy implementation worldwide. We identified approximately 1,600 interventions enforced by the end of 2015. The composition of portfolios varies across regions (e.g. between Non-OECD Europe and Africa) (figure 1(b)). A clear implementation of policy interventions is observed, however, progress slowed after 2009, and it is unclear whether this was due to policy delays or a lack of public data.[11] This significant increase, particularly prior to 2009, may be explained by the negotiations that preceded the Copenhagen Climate Change Conference of the Parties (COP 15). It has been argued that COP15 brought climate and energy policy to the top

[11] We therefore compared this trend with data from the Climate Policy Database (CPD), which is one of the most comprehensive databases we used in our study. This exercise confirmed an upward trend that peaked in 2009 (see supplementary figure 5) and a (less-steep) downward trend post-2009. The comparison also highlighted a discrepancy in the number of implemented policies for 2015. However, this is explained by the fact that the CPD includes policies that address the entire fossil fuel mix and the agricultural and forestry sectors, which are outside the scope of our study.

(b)



(c)

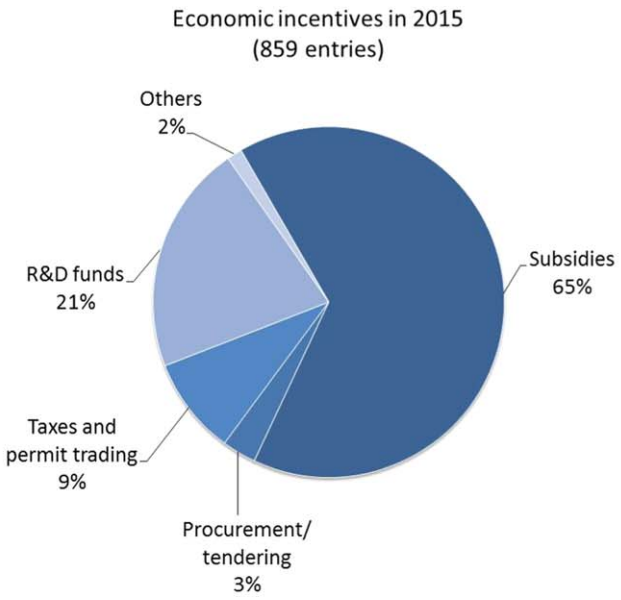


Figure 1. (Continued.)

of the political agenda [50, 51]. Over time, policy mixes have grown steadily; particularly in less-industrialised regions (e.g. Africa and Middle East) (see supplementary figure 4, available online at stacks.iop.org/ERC/1/061001/mmedia). In particular, there is stagnation in OECD North America post-2009, and recoil of policy implementation in Oceania after 2012. Relatively speaking, Oceania is the only region to demonstrate a more balanced policy mix. Emphasis on regulatory approaches can be identified mostly across OECD Europe (34%) and non-OECD Europe (38%) compared to Latin America (20%), Oceania (21%) and OECD North America (16%). While OECD Europe (741 entries), Asia (312 entries) and North America (193 entries) had the highest absolute number of enforced policies by 2015, significant relative increases were found for Africa, the Middle East and Non-OECD Europe. Compared to industrialised regions, this may be because countries in less-industrialised regions have defined their LCET policy strategies more recently. It is clear that further research is needed to identify the specific learning, persuasion, emulation and/ or harmonisation mechanisms that have historically driven the design of policy mixes across regions.

A second, striking, finding is the emphasis on economic incentives (figure 1(b)), which globally accounted for 49% of implemented policies in 2000, increasing to 53% in 2015 (see supplementary figure 2). Figure 1(c) shows that subsidies (such as tax credits, loan guarantees, direct grants, soft loans, feed-in tariffs, and accelerated depreciation) dominate. It is clear that, historically, economic incentives have diffused across most regions (see supplementary figure 4). This is consistent with the increasing role of economic thinking that has already been identified in environmental policy [52]. From this point of view, the 2009 peak noted above may also be explained by the implementation of Keynesian economic stimulus packages that followed the 2008–2009 financial crisis. These packages promoted the transition to 'green growth', and LCETs were expected to play a pivotal role [53–55]. Although the dominant use of economic incentives suggests that an economic crisis was needed to boost the market uptake of LCETs, various global studies suggest that they have not been effective. This is thought to be due to a lack of stringency and structural interdependencies between economic and emissions growth [8, 56–60]. Finally, although subsidies are very popular (figure 1(c)), there is limited empirical research into their performance [61], notably synergies and overlaps with other mitigation policies [62, 63]. Quantitative studies are thus needed to evaluate the economic efficiency and (cost-) effectiveness of subsidies compared to other policy instruments; including specific convergence mechanisms.

Third, we found that policy portfolios predominantly aim to correct market failures, while much less attention is given to behavioural factors. This is consistent with the disciplines that dominate the analysis and understanding of policy mixes targeting energy transitions, such as environmental economics [64], and the approach taken by, for example, the European Commission to decarbonise its energy system, which relies heavily on market failures and technology neutrality [65]. Our review of policies highlights that policy interventions are limited to internalising external costs, reducing financial constraints and moderating the lack of information. Behavioural interventions that focus on voluntary behavioural change (e.g. targeting perceptions and cognition) or contextual change (e.g. targeting the framing of decision making) [66] are limited and confined to information schemes only. For example, the International Energy Agency's Energy Efficiency Policies and Measures database, one of the most comprehensive archives, lists only one behavioural measure ('Energy efficiency strategy' in South Africa). At the same time, half of its nearly 2,000 entries are labelled as 'economic instruments', often referring explicitly to correcting market failures. Based on the taxonomy developed by Münscher *et al* [45] we note that behavioural-oriented policies primarily aim either to provide information (e.g. via public information campaigns or feedback) or simplify it (e.g. via labelling schemes). Despite claims of growing interest in applied behavioural science and behavioural economics among policymakers [33, 67, 68], our results suggest that policymakers have failed to take explicit account of behavioural factors via, for example, the use of social normative reference points [30]; green energy defaults [69]; the promotion of energy community platforms to foster peer-effects [70]; goal setting [66]; and commitment [71].

The results of the bottom-up analysis were comparable to national-level findings. Figure 2(a) shows that the number of city-level interventions has increased rapidly over the past decade. The Global Covenant of Mayors for Climate and Energy, which is the largest transnational municipal climate network, has registered policy commitments from 7,500 cities, targeting a total population of 681 million [72]. Similarly, implemented emission reduction activities reported to the CDP grew rapidly between 2012 and 2017. While climate actions reported in the carbonn® registry have increased—from about 400 at the end of 2010 to about 7,200 in 2017 [48, 73]– it is unclear whether this is due to increased reporting or additional activity. Figure 2(b) shows that investments in infrastructure and technological measures dominate. For example, entries in the CDP database refer to energy-efficiency measures in buildings (8%), investments in non-motorized transport infrastructure (6%), waste infrastructure (5%), low- or no-carbon energy generation (5%), and on-site renewable energy production (4%). Only a few actions explicitly target behavioural factors, notably transportation demand management (3%). Technology and infrastructure investments dominate the carbonn® registry, making up more than half of all entries [48]. Here again, there is little evidence of consideration being given to behavioural factors. Of the 3,800 mitigation actions reported in the carbonn® registry, 3,500 emission reduction activities reported to

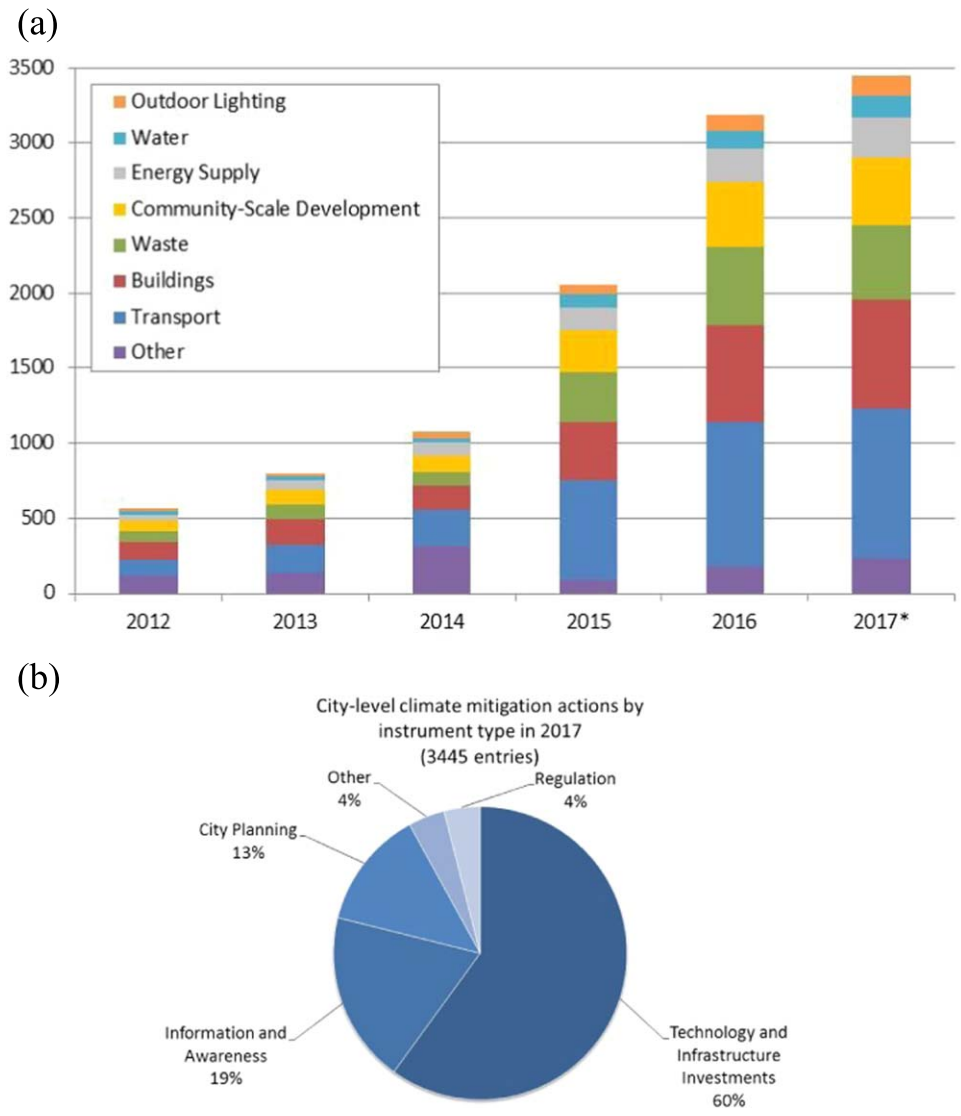


Figure 2. (a) Number of in-force city-level emission reduction actions by sector (Source: CDP). The categorisation of sectors was changed after 2014; 'community-scale development' was previously referred to as 'urban land use'. The value for 2017 includes reported actions up to September 2017. (b) Emission reduction activities by cities in 2017 (Source: CDP). 'Other' includes financial instruments, green economy measures and other unclassified activities.

the CDP in 2017, and 6,100 examples of good practices recorded by the EU Covenant of Mayors, only a handful explicitly address such factors. Examples include setting defaults for green electricity tariffs and offering sustainable transport subsidies to people experiencing salient life events (e.g. childbirth or a change of job).

The ambitious 1.5 °C target implies that 'cities must simultaneously practice 'mega mitigation' [74]. Given that cities are growing and new ones are being built at an astonishing rate, it is clear that priority should be given to the implementation of LCETs [75]. At the same time, people live, move around and consume in cities, and their behaviour(s) are a key determinant in energy use and associated carbon emissions [17]. In addition to infrastructural and institutional lock-ins, various 'behavioural' lock-ins have been already identified (e.g. a lack of ability to judge potential financial gains from LCET) [76]. Treating the urban population as a 'market actor' when designing and implementing mitigation policies runs the risk of setting the wrong priorities, and potentially wasting the behavioural leverage that is pivotal to encouraging bottom-up decarbonisation processes.

Overall, the limited evidence we found of policy interventions that explicitly address behavioural factors was confined to non-governmental actions. Typically, interventions are deployed via experiments, pilot studies or small-scale utility-driven initiatives in (mostly) industrialised countries [21, 30, 33, 66, 68, 69, 71, 77, 78]. *A priori*, this situation suggests a divide between governmental and non-governmental initiatives and indicates that local behavioural interventions may need to be coupled or coordinated with national policy instruments. However, although we hardly found explicit cases where behavioural factors inform national policy design, we acknowledge that some policies may have been informed by behavioural factors. Examples could include performance standards that have the potential to reduce choice overloads when choosing energy-consuming

products (e.g. the Top Runner Programme in Japan), or labelling programmes that can help in overcoming limited attention and heuristics (e.g. the Energy Label Programme in Europe; Fuel Economy Labels in the United States). Better-quality reporting and further research are needed to determine the role of psychology, behavioural economics and applied behavioural science in policy design. In addition, it is important to study the mechanisms that support or deter the diffusion of behavioural-oriented policy interventions.

The findings seem to support claims that there is a lack of consideration of behavioural factors in policymaking. For instance, our results suggest the persistence of a traditional, technocratic approach that emphasises economic thinking and which does not necessarily deliver effective and efficient policies [52]. The Talanoa Dialogue recognised the ineffectiveness of policy mixes already implemented, and concluded that 'despite all our [policy] efforts, greenhouse gas emissions, their concentration in the atmosphere and global average temperature, are still on the rise' [10]. However, despite the growing knowledge about the factors that enable or hinder climate mitigation actions [17, 79], the strong focus on market failures implies an ongoing assumption that energy users have clear, stable preferences over time, use all available information when deciding whether to adopt and use LCETs, and are unaffected by decision contexts [21, 41]. To some extent, our findings are confirmed by the 'good practice' inputs submitted to the Talanoa Dialogue at the COP24 [see 15]: an emphasis on economic incentives and the technology development; and little or no application of behavioural factors in the design or improvement of policies.[12] It seems that policy efforts are limited to approaches that reduce the use and implementation of LCETs to the application of economic theory [cf 80]. Consequently, one could argue that current policy is not very effective because, among several factors, it fails to explicitly take account of mounting evidence of suboptimal decision-making and normative, emotional, moral and social influences affecting energy choices and climate action [21, 30, 32, 43, 66, 78, 81–83]. With respect to our review of the documentation, the limited consideration of behavioural factors, and the lack of behavioural-oriented interventions may be driven by a lack of transdisciplinary approaches designed to support policymaking [64, 79, 84], political and ethical concerns regarding the integration of libertarian paternalistic approaches [85], and a poor understanding of what behavioural science has to offer [86–88]. A key challenge for policymakers appears to be how to (better) identify the behavioural factors that affect decision processes and choices, and understand how they can be targeted by specific policy interventions [22, 33].

4. Conclusion

The lack of progress in reducing carbon emissions, and the innumerable challenges resulting from the Paris Agreement are clear evidence that the full potential of LCETs cannot be unlocked unless policymakers urgently reconsider not only their interventions and ambitions *per se*, but also the approaches that underlie and generate these interventions. Outputs from the Talanoa Dialogue imply an urgent need to reconcile the long-term vision of the Paris Agreement with stringent, short-term national and local-level policy mixes. With due limitations, our study highlights a significant spread of policy interventions and growing emphasis on economic incentives, technology and infrastructure. If economic incentives were once considered an innovative approach to environmental policy, the political economy of the Paris Agreement is testing the theoretical merits of this approach, and challenging the optimism of advocates. Combined with a lack of stringency, experience shows no effectiveness and also a failure to bridge the policy–science gap, particularly with respect to behavioural sciences. Although there appears to be a rise in the inclusion of behavioural insights in policymaking [33], our study questions its extent –at least in terms of the problematisation of climate actions and energy choices on the demand side [79, 84]. We acknowledge that much more research on policy convergence mechanisms and better-quality reporting (e.g. on policy design and costs) are needed to further scrutinise policy efforts.[13] In addition, the incorporation of behavioural insights into policymaking is no panacea [33, 71, 89]. Nevertheless, emerging evidence suggests that policies are likely to be more (cost-) effective when they systematically take behavioural factors into account [14, 30, 32, 33, 68, 71, 88, 90, 91]. We need to seize this opportunity to complement or improve the existing policy mixes. At the COP24, the Talanoa Dialogue called 'upon everyone to act with urgency' and 'provide grounds for bold, integrated and coherent policies' [92]. We, in turn, call upon the Talanoa Dialogue (and similar initiatives) to urgently consider and promote a much more rigorous, realistic, transparent and integrated approach to design, implement and evaluate LCET policy portfolios.

[12] See supplementary material for a menu of good practices regarding specific LCET policy interventions. Compared to the outputs from the Talanoa Dialogue, this aims to provide a wider set of options. It highlights the need for policies that are simple and manageable; however, further research is needed to ascertain the effects of policies as a mix. The results of any assessment are likely to be context-specific.

[13] At the EU level, the new 'Regulation on the Governance of the Energy Union' aims to encourage reliable and transparent reporting of energy and climate policies.

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